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Final Report VUV Acousto-Optic Spectroscopy
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Summary:

The objective of our project was to adapt acousto-optic technology to produce a reflective vacuum UV (VUV) diffraction grating with an electrically tunable surface profile. We explored acoustic wave device fabrication and physical performance parameters important to VUV reflection grating spectroscopy. We optically tested surface acoustic wave and Lamb (plate) acoustic wave devices, but could not achieve devices suitable for astrophysical instrumentation within the confines of our program.

First Effort:

We obtained an existing commercial (0.8 x 7mm) 250MHz SAW device, (designed for electronics filtering applications) metalized the acoustic wave region, set up an amplified radio-frequency drive and sensor system, and probed the device with an optical laser. Positive and negative 80 line/mm, frequency tunable, SAW diffraction was successfully observed. We assembled a vacuum device testing set-up for use in the vacuum UV (1216 Angstrom). Although VUV SAW diffraction was visible, it could be recorded only at the 3 sigma level. (See Figure) The limitation on the measurement's signal to noise ratio proved to be the test beam's size (~1 mm) relative to the effective surface-wave width (0.6mm). Illumination with the oversized beam resulted in a substantial fraction of the incident flux being specularly reflected from the un-induced portion of the device. Furthermore, manufacturing marks at the perimeter of the active area were illuminated, causing stray light noise.

Investigate Commercial Fabrication Solutions:

In order to overcome the signal to noise problem, we attempted to find a larger area SAW devices with the several hundred MHz operating frequencies needed for VUV suitable line densities. Commercial production devices with these properties were not available so we investigated custom devices. We surveyed domestic and foreign manufacturers. We discovered that the "specialty SAW foundry" of choice had recently been bought by a large manufacturing concern and that research/development scale projects had been curtailed. While other SAW fabrication houses could produce custom products, the small scale of this program could not support their non-recurring engineering costs.

We briefly investigated using standard commercial micro-fab foundries, accustom to silicon processing, to make larger SAW devices. We found them loath to handle the required lithium niobate substrates, which were unfamiliar to them.

Investigate Existing Research Fabrication Solutions:

We turned our effort to obtain a larger area SAW device to the U.C. Berkeley Micro-fabrication Facility.

The Micro Electronic Mechanical Structures (MEMS) group identified a 3 x 6 mm acoustic wave device, originally designed for vapor sensing, to be suitable for our application.
The "Lamb-Wave" device has a thin (few micron) silicon-nitride membrane driven into a sheet wave oscillation.
Because the restoring mechanical force of the Lamb-Wave device's thin sheet is much less than the semi-infinite surface of a SAW device, the Lamb-Wave device can obtain larger wave amplitudes and be driven to the same wavelength at lower RF frequencies than the SAW device. The physics of Lamb devices are such that higher order fundamental frequencies have greatly attenuated, insufficient amplitudes.

The MEMS process required modification and physical inversion to make the smooth membrane side available for optical diffraction:
One side of the Lamb wave membrane has a rough piezo material coating and the other side is molecularly smooth due to the fabrication process.
The Lamb device was produced, mounted, coupled to a special radio-frequency drive and isolated monitor circuit and then optically probed with visible laser light.
The optical characterization found large Lamb wave amplitude but the fundamental surface wave density (10 lines/mm) was found to be almost an order of magnitude smaller than the design density.
The low wave density means that diffracted radiation would have a small angle of diffraction and consequently discrimination of the diffracted and specular VUV radiation would be impossible in our facility.

We consulted with the MEMS group about our result.
They postulated that because the few micron membrane thickness is comparable to our (attempted) driven wavelength, the wave could be in some kind of transition region, with magnitude and wave-speed in between that of a surface and a plate wave device.
Our graduate student conducted an extensive literature and mathematical study about the propagation of surface and plate waves under conditions similar to our application. Although he could not describe the behavior of our device in closed form, he concluded that operation in the transition region was indeed likely.

Investigate Novel Research Fabrication Solutions:

We held discussions with MEMS regarding possible fabrication of a new custom large-area device that would accommodated for, and possibly take advantage of, the transition from surface to plate waves.
Production of the new device would require all new substrate masks to change the membrane size and accommodate the shorter wavelength, as well as a new transducer mask.
Several full run wafer processes, with staff facility support, would be required, as well as the run and test iterations typically required to establish a new fabrication method.
The scope and cost of this effort was deemed well beyond our program's resources.

Conclusion:

The development of surface acoustic wave devices with properties suitable for VUV astronomical instrumentation appear theoretically possible but require the support of specialized micro-fabrication production facilities that exceeded the scope of our program.

The top panel show a profile of a beam incident on the
SAW device with the the RF driving frequency ON and then OFF.

The bottom panel show the difference between the SAW ON and SAW OFF recordings.
The shaded area under the solid line shows the net signal due to
first order diffracted radiation caused by surface acoustic waves.
The dashed lines show the noise level per pixel.